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All-Optical NOT Logic Gate Based on Photonic Crystals

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ABSTRACT

A novel scheme for implementation of all-optical NOT logic gate based on photonic crystal ring resonator has been proposed. Photonic crystal is comprised of two-dimensional square lattice of dielectric rods in air substrate. Indium phosphide with a refractive index of 3.1 is adopted as the material of the rods. The finite different time domain (FDTD) and plane wave Expansion (PWE) methods are used to analyze the behavior of the structure. The simulation results show that the contrast ratio is 10.97dB for NOT gate. Moreover, the operational wavelength of the input ports is 1.55µm. Since the structure has a simple geometric shape with clear operating principle, it is potentially applicable for photonic integrated circuits.

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1. INTRODUCTION

All-optical logic gates are key components in all-optical signal processing techniques. In recent years, the demands for all-optical signal processing techniques in telecommunication systems are rapidly increasing. It is now accepted that digital electronics is not able to respond to these demands in the future. In order to response this demands, many efforts have been performed. All-optical logic gates with high performance speed play a main role in signal processing and optical networks. Different structures have so far been presented to recognize the performance of all-optical logic gates. Initially, all optical logic gates based on semiconductor optical amplifier properties (SOA) were reported [1]-[3]. However, some limitations such as latency time, power consumption, speed and size of these structures cause it is used less. Various proposed structures differ in the design, material, structure, operation wavelength, operation speed, power consumption and easy to integrated. In order to optimize these characteristics All-optical logic gates based on photonic crystal was considered and investigated.

APhotonic crystals are dielectric material that the dielectric constant is periodically varied in space. The light waves could not propagate through the photonic crystals for some frequency ranges, this frequency range is called forbidden band gap. The structures of photonic crystal logic gate benefits various characteristics of photonic crystals [4]-[13].

In this paper, the performance of all-optical NOT logic gate based on photonic crystals ring resonator has been published. Photonic crystal structure is made up of square lattice of dielectric rods in air substrate. The distinction between logical "zero" and "one" is improved and power consumption has also been declined in this scheme. One of the important characteristics in integrating photonic crystal structures is the identically of wavelength for optical signal. As we will see onwards, this structure has the potentiality to be applied in photonic integrated circuits. Electromagnetic wave propagation in the time domain was simulated using Finite difference time domain (FDTD) and photonic bad gap has been calculated using plane wave expansion (PWE) [14]-[15].

2. OPERATION PRINCIPLE AND STRUCTURE ANALYSIS

In this paper, we propose a NOT logic gate based on two dimensional square lattice photonic crystals composed of cylindrical Indium phosphide (*InP*) rods of dielectric constant of 9.61 (ε_r=9.61) in air substrate as shown in Figure 1. The dispersion diagram of this material for rods radius equals r=0.2a, which a is the lattice constant has been calculated using plane wave expansion. The dispersion diagram of the concerned structure for TM modes has been shown in Figure 2.

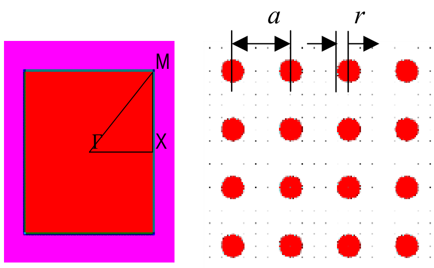


Figure 1. (Color online) An array of two dimensional square lattice photonic crystal composed of cylindrical Indium phosphide rods in air, where r is the radius and a is the lattice constant of the Indium phosphide rods, respectively.

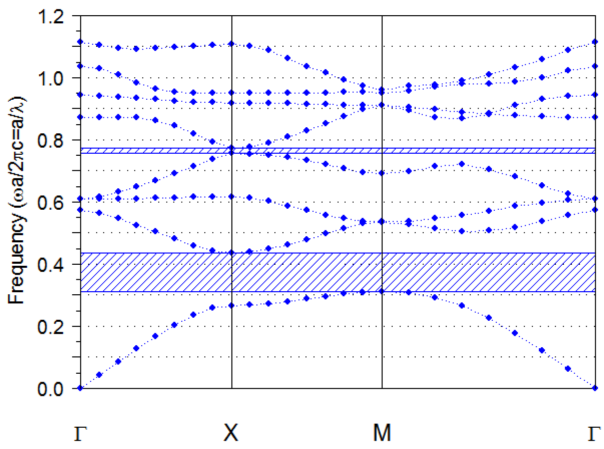


Figure 2. (Color online) Band diagram in a square lattice of Indium phosphide rods (ε = 9.61) in the air substrate for TM modes.

According to the band diagram, a good forbidden band gap was obtained in the normalized frequency range of 0.3116≤λ/a≤ 0.4365 for TM mode. Therefore, band gap width is 0.1249 and normalized central frequency of band gap (a/λ) is 0.37405.

The schematic diagram of the proposed NOT logic gate is shown in Figure 3.Since, the output is ON when the input is OFF for NOT logic gate, therefore we need to a control signal for designation of this gate. In the concerned structure, the inputs are shown with *I* and *C* and the output is shown with NOT. The input light comes from *I* port and the control signal comes from *C* port. The control signal has the same power of input (P_0) and will applied to the *C* port whether the input be ON or OFF. In the concerned structure the ring radius is 3a and rods radius is 0.2a. Four rods were put in the corners of the ring in order that the effect of inverse scattering of waves in the corners of the ring is removed and resonance performance inside the ring is done easily. The dimension of the structure is about 12µm × 12µm.

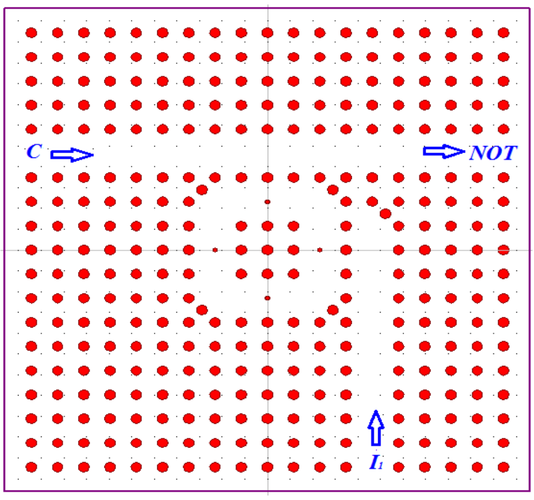


Figure 3. (Color online) Schematic structure of proposed NOT gate.

To obtain resonance frequency of the ring, the transmission spectra should be studied. The normalized transmission spectra of the structure has been shown in Figure 4. The resonant frequency of the ring resonator is in 0.376*a*/*λ*. Therefore, since the presented structure has been designed for the application in 1550nm wavelength, the structure lattice constant is achieved *a*=0.5943µm.

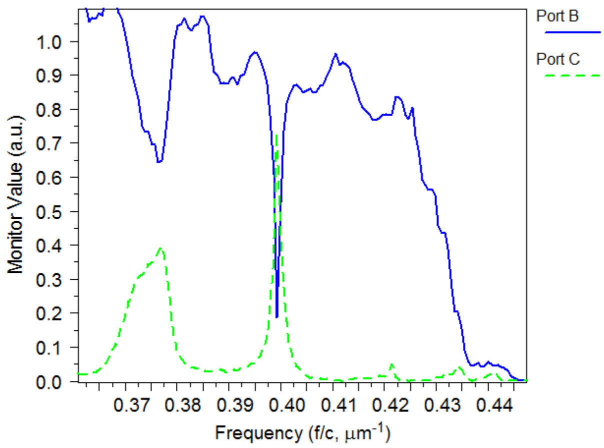
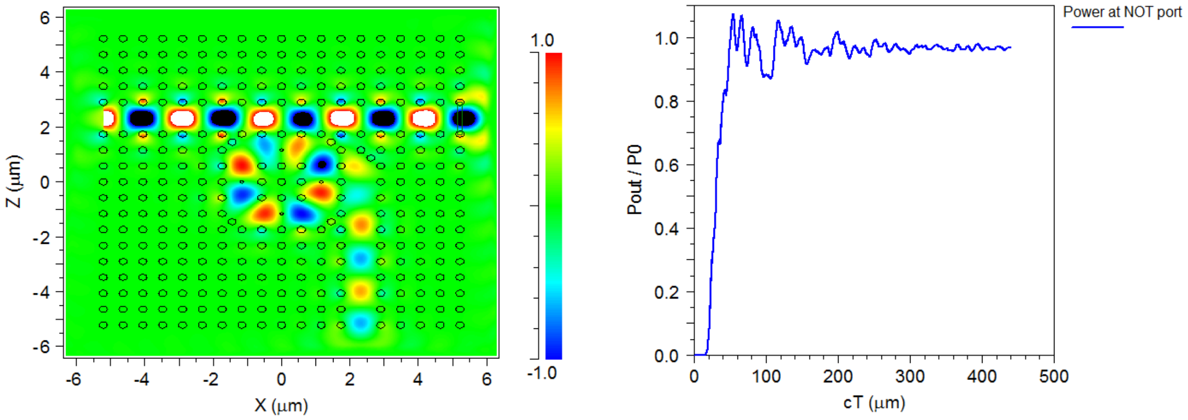


Figure 4. (Color online) The transmission spectrum of the ring resonator.

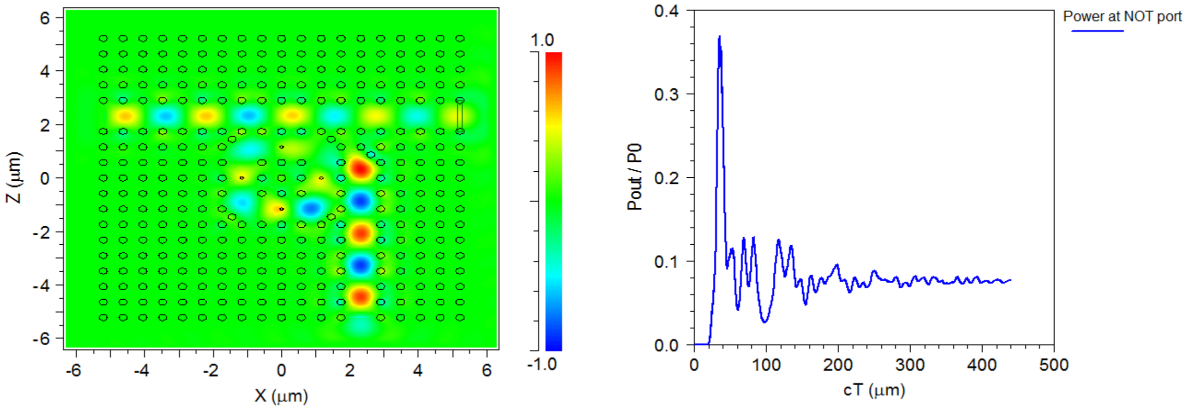
3. RESULTS AND ANALYSIS

The computational simulation is carried out by using a finite-difference time-domain (FDTD) method for the different combinations of the inputs. On the condition that the input port (*I*) is "OFF", the control signal (*C*) makes the output to be "ON". At the other hand, when the input port (*I*) is "ON", the light comes from this port, will be coupled in the resonator due to the fact that the light is inserted with a resonant wavelength. In this state, the control (*C*) and input beams interfere destructively. Figure 5(a) shows the distribution of electrical field when the input is "OFF". In this case, as the output power level in Figure 5(b) shows, the time of achieving NOT output to constancy is 0.4ps and its power level is $0.96P_0$, which has been regarded equal to logical level of "zero". Figure 6(a) shows the distribution of electrical field when the input is "ON". In this case, as the output power level in Figure 6(b) shows, it remains in its constant state after 0.84ps to the output power of $0.08P_0$, which has been considered as logical "zero". The presented design has the potentiality for the implementation of all-optical NOT logic gate.



(a) (b)

Figure 5. (Color online) a) the distribution of electrical field when the input is OFF, b) its output power level.



(a) (b)

Figure 6. (Color online) a) the distribution of electrical field when the input is OFF, b) its output power level.

Table 1 shows the level of output power of NOT logic gate. Also, given the power levels, the ratio of the contrast between logical "zero" and "one" for NOT gate equals to 10.79dB. The maximum time to reach a steady state of different combinations for the NOT operator is 0.84ps. As a result, the speed of structure operator is obtained as 1.19Tb/s.

Table 1. Truth Table and Consumed Power of the Proposed NOT Gate

I		**C**		**NOT**		
Logic level	**P**	**Logic level**	**P**	**Logic level**	**P**	**T_d (ps)**
0	0	1	P_0	1	$0.96P_0$	0.4
1	P_0	1	P_0	0	$0.08P_0$	0.84

4. CONCLUSION

A design for the implementation of all-optical NOT logic gate based on ring resonator of photonic crystal has been reviewed in this article. Photonic crystal is comprised of two-dimensional square lattice of dielectric rods in air substrate. The application structure in 1.55µm wavelength was designed and its lattice constant is achieved a=0.5943µm. The operation speed of structure equals to 1.19Tb/s and the contrast ratio between logic "Zero" and "One" levels was achieved 10.79 dB and 5.67 dB. Since the structure has a certain performance with optimum dimension of almost 12μm × 12μm. Therefore, the presented design has the potentiality to be applied in optical integration circuits.

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Majid Ghadrdan has received his B.Sc and M.Sc degrees in electrical engineering from the University of Sistan and Baluchestan, Zahedan, Iran in 2010 and 2012, respectively. His research interests include optoelectronics, photonic band gap structures and applications of photonic integrated circuits.

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